Juvenile Chinook Salmon and Adult Delta Smelt Salvage Efficiency at the Tracy Fish Collection Facility During VAMP: Effects of Primary Bypass Ratio on the Whole Facility Efficiency

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Study Summary

California exports approximately 7.3 billion m^3 of water annually from the Sacramento/San Joaquin River Delta (Delta) to Central and Southern California for agriculture, municipal, and industrial needs. The majority of water is diverted by two pumping facilities in the south Delta: Jones Pumping Plant (JPP) owned by the federal government's Bureau of Reclamation (Reclamation) and Harvey O. Banks Delta Pumping Plant (BPP) owned by the California Department of Water Resources. Both sites are equipped with fish salvage facilities upstream of the pumping plants to reduce the number of fish entrained through the pumps. The fish facilities were designed to capture juvenile Chinook salmon and striped bass (USBR 1956).

The federal Tracy Fish Collection Facility (TFCF) and state Skinner Delta Fish Protective Facility (SDFPF) use a behavioral louver-bypass system to guide fish out of the canal and into collection tanks, where they are held until transported to the northern Delta. At the TFCF, fish enter through a trashrack with 58-mm-wide bar spacing and travel through the 25.6-m-wide primary channel to one of four bypass entrances along the primary louvers. Once inside the bypass entrance, fish are guided downward into the underground bypass tube leading to the secondary channel where fish encounter a second set of louvers. Fish guided successfully by these louvers are diverted to holding tanks. Two or three times daily, fish are removed from the holding tanks with a bucket and transferred to a 9000-L fish-haul truck for release back to the Delta.

The efficiency of louvering system~~s~~ to properly guide fish through each facility is strongly dependent on the water velocity in the facilities primary and secondary channels (Bates *et al*. 1960, DWR 1967). In addition, achieving an appropriate bypass ratio (BR; >1.0), defined as the ratio of the water velocity entering the bypass opening to the average channel velocity upstream of the louvers, is reported to be critical in promoting fish to enter a bypass (Bates *et al*.1960, DWR 1967). High secondary channel louver efficiency (>90%) for Chinook salmon (*Oncorhynchus tshawytscha*) have been achieved when BR is approximately between 1.0 and 1.4 when channel velocity is 1.0–3.5 ft/s (Bates *et al*. 1960). Interestingly, DWR (1967) tested secondary louver efficiencies at the TFCF over a range of BR from 1.0 to 2.6 and found as bypass ratio continued to increase secondary louver efficiency also increased for juvenile striped bass (*Morone saxatilis*) and adult smelt. Three species of smelt were lumped together during these tests and the data were not exclusively for delta smelt (*Hypomesus transpacificus*). Salmon did not show this similar trend but efficiency only declined a small amount (~5%) for the higher bypass ratios. A similar trend in salmon louver efficiency was found at the SDFPF and salmon louver efficiency was high between 1.0 and 1.6, but not statistically different over this range (DWR and CDFG 1973).

Water velocity and BR are such important components affecting the TFCF salvage efficiency, that special operating guidelines have been specified in multiple regulatory criteria (SWRCB Decision-1845, NMFS 2004 Biological Opinion, and the California Department of Fish and Game Agreement 1992). Primary channel velocity is controlled by JPP and not by pumps at the TFCF, and there are no legal requirements for maintaining a set primary velocity even though one was accidentally incorporated into NMFS 2004 Biological Opinion. Minimal current facility criteria, as stipulated by D-1485, are as follows:

- Primary BR always >1.0 (average primary bypass entrance velocity/ average primary channel velocity)
- Secondary BR always >1.0 (average secondary bypass entrance velocity/ average secondary channel velocity)
- Secondary Velocity <2.5 ft/s June through August
- Secondary Velocity 3.0 to 3.5 ft/s February through May

In addition to salvage facilities, government agencies have used other management tools to improve the survival rate of Chinook salmon emigrating down the San Joaquin River. Salmon migrate downriver many months of the year but their numbers peak in March–May. To increase survival of emigrating fish, three management strategies are utilized from approximately April 15–May 15: (1) Pumping is reduced at the JPP and BPP to reduce the number of salmon diverted towards the pumping plants, (2) Water flow in the San Joaquin River is increased to increase the rate of downstream salmon migration, (3) Manmade barriers are built across the Delta channels to divert water flow and fish away from pump intakes in the south Delta. This management program is known as the Vernalis Adaptive Management Program (VAMP) and is required by California State Water Resources Control Board Decision 1641. The first year of formal monitoring was completed in 2000 (SJRGA 2000).

VAMP was initiated to improve the overall survival of Delta salmon. However, salvage efficiency for salmon and smelt entering the TFCF during VAMP may be much lower than under normal operations. During normal operations, five pumps are running at the JPP and keep the primary channel velocity around 2.5–3.0 ft/s. During VAMP, the JPP operates with one pump, and the TFCF primary flow is approximately 0.5 ft/s. Reduced pumping likely entrains fewer salmon; however, fish salvage efficiency during VAMP is likely to have declined due to slow water velocity in the primary channel and in the entrance to the four bypasses. Bates and Vinsonhaler (1956) state that their previous work with salmon in test flumes show salmon are successfully guided by louvers when exposed to flows down to 0.2 ft/s. However, lower primary velocities likely result in delayed passage rates as this has been demonstrated in the secondary channel for striped bass (DWR 1967B). In addition, Sutphin and Bridges (2008) documented that for high capture efficiency (~60%) of juvenile salmon and splittail (*Pogonichthys macrolepidotus*) going into bypass 4 during VAMP, bypass intake velocity needs to be >2 ft/s. This means that under VAMP conditions the primary BR should be near 5.0 and not the recommended 1.6 for maximum facility efficiency.

The main goal of this study is to assess how the primary-BR influences whole facility and primary channel louvering efficiency of juvenile Chinook salmon and adult delta smelt during low primary channel velocities.

This is year two of our study. In the first year we focused on salmon and completed 80–90% of the proposed work. We found that for salmon the holding tank buckets were nearly 100% efficient, secondary velocity drastically influences travel time, and primary bypass ratios much greater than the standard 1.6 provide better salvage efficiency. In addition, a few trials with delta smelt were collected but work next fiscal year must focus on collecting data for delta smelt.

Problem Statement

The operators at the TFCF have historically set the primary bypass ratio to 1.6 during VAMP and allowed the secondary channel velocity to drop below criteria. This may have greatly reduced the potential salvage efficiency for the TFCF. Data collected from this project will provide critical information for establishing new BR criteria for the TFCF.

Goals and Hypotheses

Goals:

1. Measure collection efficiency of new bucket in holding tanks.

2. Determine if the historical operating criteria for the TFCF provides peak salvage efficiency for delta smelt adults and juvenile Chinook salmon.

3. Develop a conceptual model for how bypass ratio in the primary channel influences whole facility efficiency for the five operating scenarios at the JPP.

Hypotheses:

1. There is a significant positive relationship between secondary bypass ratio and secondary salvage efficiency when the bypass ratio is between 0–1 and 1–4.

2. There is a significant positive relationship between the primary bypass ratio and primary louver efficiency between bypass ratios of 1–6.

3. There is a significant difference in whole facility efficiency between two operating scenarios: Setting the primary bypass ratio to 1.6 and allow the

secondary velocity to vary vs. when you set the secondary velocity to criteria and allow the primary bypass ratio to vary.

Methods/Approach

Efficiency Experiments

Field experiments will be completed during the months of March–June and the study should be completed by December 2011. Most of the tests will be run when Jones Pumping Plant (JPP) is operating with one pump. During low pumping the TFCF primary channel average water velocity is approximately 0–0.3 m/s and our target velocity for testing is >0.15 m/s. Primary channel velocities slower than this cause extreme delays in fish passage. Adult delta smelt (70–100 mm FL) will be attained from the UC Davis' Fish Culture and Conservation Lab (FCCL) and juvenile hatchery Chinook salmon (70–110 mm FL) will come from one of the local hatcheries (Mokelumne, Nimbus, Orville, or Coleman). For all experiments, fish will be tagged in the fins (dorsal, anal, or caudal) with the NewWest Technology Photonic Marking Solution (Sutphin 2008). All fish will be held in 757-L, black, 1.2-m-diameter polyethylene, tanks receiving cleaned (ozonated) delta water within ± 1 °C of ambient Delta temperature. Each tank will be gently aerated with a small airstone (1.5 in x 1.5 in x 3 in) to keep oxygen levels above 7 ppm, and tanks will be covered with shade cloth to keep birds out. Chinook salmon will be fed Silvercup Brand food (1.5-mm steelhead pellet), and delta smelt will be fed Lancy Diet (400 micrometer) at 2% body weight per day. Both species will be handled with fine mesh dip nets and transported and released into the experiments with black 20-L buckets. Buckets are lowered by rope and tipped over at water surface level so that released fish are gently placed into position for all tests. Each day that a trial is completed in the secondary channel the louvers will be cleaned and the predators removed.

This study will consist of four experiments.

Experiment 1

The 10-min count bucket has been recently modified and it is not known what the loss rate is for this device when it is collecting a sample of fish from the holding tanks. Before it is used it should be tested to verify it does not leak fish. Test fish (Chinook salmon and delta smelt) will be released directly into holding tanks 2 and 4 before experiments begin to verify the holding tanks and bucket do not leak for fusiform body shaped fish. Four releases per tank will be completed with 25 fish released per injection. The tanks will collect water for 10 min and then be drained to collect fish. If the mean recovery efficiency is not above 95% then the bucket must be modified to prevent leaking and retested. Once the buckets pass minimum efficiency criteria the bucket will then be considered 100% efficient for the calculations. From previous experience running experiments at the TFCF it is possible to lose 1 or 2 test fish per sample due to fish getting stuck in the corners of the screen's support structure and in between the wall and water quality pipes. It is not logistically possible to run an efficiency test ever time the bucket is lifted out of the tank during a test as this would require too many fish. However, a small group of fish (10) will be placed in each tank as a quality control indicator of bucket failure. This method is further explained below under Experiment 2.

Experiment 2

The second experiment will look at secondary bypass ratio's influence of secondary louver efficiency at three velocities (0.3, 0.6, 0.9 m/s) during daylight hours. This range of velocity covers normal operating velocities. The purpose of this experiment is to see if secondary bypass ratio can be used to predict louver efficiency above bypass ratios of 1.0 at each channel velocity. If there is no significant relationship, then the bypass ratio in experiment 3 will be specified to be between 1.2–1.6 (the operating standard). If there is a significant positive relationship then the bypass ratio will be mandated to be as high as possible.

The secondary channel and holding tanks will be stabilized ($\pm$ 0.05 m/s) at the target velocity and bypass ratio prior to each trial. Hydraulic conditions will be documented at the start of each test. Twenty fish will be released at the head of the secondary channel and the number of fish captured in the holding tank and sieve net will be counted after 20 min. Prior experience with pilot tests have shown trials only need to be 20 min long because >90% of the fish that participate in a trial do so within 20 min at the standard salmonid velocity criteria. Less than 90% of the fish will participate in each 20-min trial at the slower velocities. After the conclusion of each trial all VC pumps will be turned on for 2 min to wash remaining test fish out of the secondary channel to prevent interference with the subsequent trials and then the next test will commence. One target velocity will be chosen for testing each day and the bypass ratio to test for each trial will be randomized. Thirty trials will be completed at each velocity to generate a regression showing secondary louver efficiency as a function of secondary bypass ratio. The bypass ratios chosen to test for each trial will be randomized and will fall within the range of 0.9–4.0. Specific bypass ratios will not be tested as the facility does not operate by holding the primary or secondary bypass ratio constant. Holding the bypass ratio at a constant condition (*i.e.*, 1.2, 1.4, 1.6) is not practical for operating the TFCF as tidal influences quickly change the BR and require constant adjustment (every 15 min) by the operators.

Quality control holding tank fish will be inserted in every holding tank sample (10 fish/tank) to determine if the holding tank bucket was sealed and seated properly. In the past, the bucket's center drain valve has been stuck in the open position and we lost our sample without our knowledge. In addition, the buckets lip does not always seat properly within the drain mount and fish can slide under the lip of the bucket. To prevent these problems from interfering with test results, we will use the recovery of injected controls to judge if the sample has been compromised. If we do not collect at least 8 of the 10 fish injected then the sample must be discarded. Based on previous experience it is impossible to recover 100% of these control fish on a reliable basis as individual fish can be wedged into corners along the screen or piping along the walls of the tank.

It is not possible to release healthy quality control fish in front of the secondary channel sieve net to verify that the net is fishing properly and not leaking. This has been tried in the past and there are always approximately 5–20 % of the fish that swim upstream and hide behind the louvers. To help ensure the sieve net does not leak, the net will be inspected for holes each morning and mended if necessary. In addition, to indicate the net frame is completely resting on the bottom, there are guide marks on the concrete wall.

Experiment 3

The third experiment will be to run whole facility efficiency trials during VAMP, or when pumping is reduced to 1 pump at the JPP, for Chinook salmon and delta smelt across the full range of secondary velocities. These data will be used to generate regression equations for predicting facility efficiencies based on primary bypass entrance velocity, primary channel BR, and secondary velocity during VAMP. Based on the work by Sutphin and Bridges (2008) we are anticipating there is a threshold velocity value that must be reached at the primary bypass entrance before fish will descend inside the bypass and travel towards the secondary channel. This threshold velocity may be comparable to the burst or prolonged swimming speed for each species and should be clearly visible when plotting the trends.

For each day of testing, six trials will be completed during the day and they will evenly cover the entire range of possible primary BR that are >1. Secondary channel BR will be set according to the data in experiment 2. All six trials will be run during the incoming tide so that the primary channel velocity is nearly constant 0.5–0.8 ft/s for all days of testing. Replicate trials for each secondary channel velocity tested will take place over a range of stage heights due to tidal influences. Each trial will be monitored for 30 min by checking holding tank and sieve net samples. Previous experience with testing these two species has shown that >50% of the fish participating in these types of experiments come in within the first 30 min when operating conditions are favorable. One hundred and forty fish will be used for each trial. One hundred fish will be divided into four groups (25) and inserted at the head of each louver bay. Louver bay 1 and 4 are the furthest upstream and downstream respectively. Forty fish will be inserted at the head of the secondary channel.

The sample size for the primary channel injections was selected for two reasons. First, during normal salvage operations we typically collect 1–15 salmon in a 10-min count every 2 h. This means 12–180 fish typically end up in the holding tank every 2 h. In the past, the salmon louver efficiency has been approximately 60% and this means that for every 2 h of facility operation 20–300 fish enter through the trashrack (Karp *et al.*1995). Therefore, the release group size selected for these tests is similar to the number of fish naturally entering the facility. It is important not to release groups of fish that would saturate the predators inside the facility and remove them from the efficiency estimate. Second, if 100 fish are released downstream of the trashrack we will recover enough fish in the holding tanks to still make comparisons between treatments and have enough fish for the number of replicates needed.

Experiment 4

The fourth experiment will investigate operating the facility under two different scenarios (back-to-back paired trails) each for 80 min to determine if whole facility efficiencies are equal. This test will only be completed if no clear trend in whole facility efficiency vs. bypass entrance velocity is identified from experiment 3. This experiment will utilize nearly the same methods as in experiment 3. The reason for completing these paired tests is that the CDFG 1992 operating agreement expired and the facility operation was reverted back to the criteria of D-1485. Test species for this experiment are Chinook salmon and delta smelt. Method one is to set the primary bypass ratio at 1.6 and allow the secondary channel velocity to drop below criteria (3.0–3.5 ft/s). Method two is to set the secondary velocity at 3.0 ft/s and allow the primary BR to go above the traditional criteria (1.6). In each method of operation, the secondary bypass ratio will be kept above the criteria established in the first experiment. The goal of this test is to be able to detect at least a 30% difference in whole facility efficiency between methods. Such a large difference in efficiency is expected based on previous work (Sutphin and Bridges 2008); consequently, only 10 paired trials will be completed. The estimated power of this test is above 0.8.

Test fish (Chinook salmon and delta smelt) will be released behind the trashrack and recovered in the holding tanks and secondary sieve net. Holding tank and sieve net samples will be collected every 20 min for up to 80 min. Hydraulic and environmental parameters (*i.e.*, stage height, tide, turbidity, primary channel water velocity, and light levels) all change rapidly over the course of the day and back-to-back paired, short duration trial are the best way to keep these variables nearly constant. Paired tests will be completed as best as possible over the complete tidal cycle and tidal range. Testing will only be completed during daylight hours.

One hundred and forty fish will be used for each trial. One hundred fish will be divided into four groups (25) and inserted at the head of each louver bay. Forty fish will be inserted at the head of the secondary channel.

Fish Source, Tagging and Care

Delta smelt will be obtained from the Fish Conservation and Culture Laboratory (UC-Davis facility located in Byron, California). Chinook salmon will come from one of the state or federal hatcheries (Mokelumne, Nimbus, Orville, or Coleman). Fish will be marked using fluorescent pigments (BIOMETRIX System-1000 Pow'r-jet Powered Injector, Photonic Marking Solution, NewWest Technology, Santa Rosa) approximately 1 week prior to insertions. Each replicate will be assigned a unique tag to differentiate between fish released at different locations and times. Fish will be held in outdoor tanks (4 ft diameter) at the TAF under ambient conditions. Test fish will be reared in Delta water temperatures for at least 1 week prior to insertion.

Data Analysis/Interpretation

For all experiments the formulas below will be used to calculate the whole facility efficiency (WFE), secondary louver efficiency (SLE), primary louver efficiency (PLE), and holding tank efficiency (HTE). Since there is no way to capture fish behind the primary louvers it is assumed that all released fish into the primary channel participate in the experiment. Fish passing through the secondary louvers are captured by a sieve net that samples all water passing through the secondary channel louvers. The mesh size (2 mm) on this net is small enough to guarantee that fish (70–120 mm FL) will not pass through the net. Each morning before the tests the net is inspected for holes; therefore, the sieve net efficiency is assumed to be 100%. Holding tank and bucket efficiency will be tested before the experiments begin to verify their efficiency is within 95–100%. The efficiency calculations are as follows:

TR = Fish released behind trashrack at the front of the facility
HT = Holding Tank
SN = Sieve Net in Secondary Channel behind louvers

rec = recovered fish
rel = released fish at start of experiment

$$HTE = \frac{HTrec}{HTrel} \times 100$$ (this will be assumed 100% once the control test is completed)

$$SLE = \frac{(HTrec/HTE/100)}{((HTrec/HTE/100)+SNrec)} \times 100$$

$$WFE = \frac{HTrec}{TRrel} \times 100$$

$$WFE = \frac{PLE*SLE*HTE}{10{,}000}$$

$$PLE = \frac{WFE/(SLE*HTE)}{10{,}000}$$

In experiment two, least squared linear regressions will be used to evaluate if there is a significant positive relationship between secondary louver efficiency and bypass ratios above one at each of the three secondary channel velocities tested. Bypass ratios above and below one will be evaluated separately.

In experiment three, the whole facility efficiency will be plotted against primary channel BR and primary bypass entrance velocity to look at trends in the data. It is not known if whole facility efficiency will gradually or abruptly rise as BR increases between one and four. In addition it is not known if whole facility efficiency plateaus or peaks as BR increases above one. A step change in efficiency has historically been reported to take place when the BR is near one and this is why facility operating criteria stipulates that the BR must be above one. Based on the results from Sutphin and Bridges (2008), we are expecting to see a large step increase in efficiency once the threshold velocity has been exceeded in the entrance of the primary bypass and this should not happen until the BR is well beyond 1.0. The primary bypass entrance velocity where the step change in whole facility efficiency occurs will be determined. Least squared liner regression will be used to determine if there is a predictable relationship between whole facility efficiency and primary bypass entrance velocity before and after the threshold value.

In experiment four, a paired t-test will be used to evaluate if the whole facility efficiency between the two operational methods discussed above are equal. This test is appropriate as it will remove most of the environmental and hydraulic variability differences between the pairs. A high degree of variability between the pairs is expected as stage height, light level, turbidity, and debris loads all likely to change between trials. If the data does not meet the assumptions of the test a non-parametric alternative will be used (Wilcoxon paired-sample test).

Coordination and Collaboration

This experiment will be coordinated with the TFCF staff, the UC Davis delta smelt Fish Culture and Conservation Lab, and the interagency TTAT group.

Endangered Species Concerns

Incidental take of Winter-run Chinook salmon, steelhead (*Oncorhynchus mykiss*), and delta smelt will be returned to Delta waters as quickly as possible. Totals numbers of each species will be recorded and sent to the reporting agencies. A NMFS Section 10 permit will be prepared and submitted by November 2008.

Dissemination of Results (Deliverables and Outcomes)

Preliminary results will be available by August 2009. Final data collection will not be completed until at least June 2010 and a Tracy Series Report will be available for review by December 2010.

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